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Item No. 001AK

Technical Progress Report

Development of a Low Noise 10 K J-T Refrigeration System

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MMR Technologies, Inc.
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Prepared by :

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President

1.0 Introduction

This report outlines the tasks which are presently underway or which will be undertaken on ONR contract N00014-86-C-0301 Modification Number P00003 for the period of September 1, 1989 through August 31, 1990. The contract was received on September 26, 1989 and is effective September 1, 1989. The tasks reviewed here are a continuation of studies initiated under ONR Contract N00014-86-C-0301 which was completed on July 15, 1989.

1.1 Purpose

The purpose of this contract extension is the continuation of the development of a compact, microminiature, low noise, closed cycle, Joule-Thomson refrigeration system for 10K operation for use in infra-red sensing, low noise microwave signal detection and high speed superconducting electronic data processing.

1.2 Background

The purpose of cooling many of the above types of sensors is to improve their signal-to-noise figure. However, mechanical refrigeration systems have proved troublesome because of microphonics, thermophonics and temperature fluctuations which interfere with the low noise behaviour of the devices. Microminiature Joule-Thomson refrigerators, which are fabricated by etching fine gas channels into glass substrates, on the other hand, have remarkably low noise characteristics because of their rigid structure and the absence of moving parts in the cold end. In the 80K temperature range they have found widespread use in instrumentation where extremely quiet operation is essential.

The present contract is for continuation of the development of a refrigeration system to extend this capability (80K) to the temperature region near 10K. At these very low temperatures the opportunity exists for operation of improved infra-red sensing devices, very low noise microwave detectors and for the utilization of the many superconducting devices which have been developed in the last decade based on NbN technology.

1.3 Initial Report

This report summarises work presently underway, which was continued at MMR's expense, on this project during the period of July 15, 1989 to September 1, 1989 even though the work was not funded during that period. The report also outlines work scheduled for completion during the remaining period of the contract. Work is continuing in the following areas:

a) Ongoing refrigerator design and development,
b) Compressor assembly and test
c) Implementation of gas cleansing techniques
d) System integration.

2.0 Program Status as of Effective Date of Contract

2.1 Refrigerator design, fabrication and test

Prototype fabrication and test, design refinement based on test results, and computer analysis have improved the performance of the two stage refrigerator to the point where empirically determined, "fine tuning" design changes are expected to yield the required performance.

The most time consuming process in the fabrication of the circular refrigerators is the cutting of the circular glass disks and the various countoured sections to separate the different layers of the refrigerator. Until now we have used specially fabricated metal masks and the dry abrasive etching process to fabricate the refrigerator pieces, but wear at the edges or slight misalignment or movement of the mask during etching can result in a damaged substrate or a minute leak after bonding.

The use of a computer controlled, miniature water knife will speed up and significantly simplify the refrigerator fabrication process.

2.2 Compressor Development, Assembly and Test

The compressor design has been completed and tested and the design revised to improve performance.

2.3 Gas Cleaning System, Test and Integration

Tests have been performed utilizing several gas cleaning technologies. A small zeolite filter has been used to trap condensible impurities in the nitrogen, hydrogen and helium gas streams. In the past, the cleaning of the latter two gases has been done with filters cooled with liquid nitrogen. Tests have been done to investigate filter materials capable of operating at room temperature, which would clean the hydrogen and helium gases to a level suficient to prevent clogging of these stages during prolonged operation of the refrigerator. The objective is to filter these gases with an absorber which acts irreversibly with the impurity gases which may be present. It has become clear that filtering using getters is a desired approach. In such a gas cleaner, the gas is passed over a heated reactive metal getter. All but the noble gases combine with the getter at these elevated temperatures and are irreversibly removed from the gas stream. This type of filters has been acquired and tested. The filter uses a Zr-V-Fe getter which is heated to and

maintained at a temperature of 450°C. Tests with this filter indicated that the filter reduced the moisture content of Argon to well below 0.2 ppm but contamination was still present in the form of residual moisture in the gas lines and fittings located after the filter. A stricter protocol for precleaning the gas lines has been developed. The use of a manually reversible, zeolite filter assembly in concert with the getter has been investigated with promising results.

2.4 Software Development

Computer models have been developed to provide a theoretical analysis of the refrigerator operation. It has become apparent that in order to use the complex Linde cycle for the hydrogen and helium portions of the cooler, it is necessary to take into account the variations of the density and viscosity of the gases at their lowest temperatures. The importance of this in the Linde cycle lies in the fact that in this cycle the gas is expanded twice. To take these factors into account we have modified the master refrigerator program to allow computation of the flows under various conditions of the operation of the refrigerator. Continued development of the software package to compute the mass flows in a Joule-Thomson refrigerator taking into account the temperature and surface roughness of the different zones of the refrigerator has been developed to provide a better design tool for the development of the lower temperature stages of the refrigerator.

3.0 Statement of Work

3.1 Refrigerator Development

Work will continue in the fabrication and test area and we expect to complete the testing of the 20K refrigerator within the next two months and as soon as this is complete and adequately tested we will advance to the three stage refrigerator configuration. The recent design changes utilized in the new MMR 65K refrigerator will be incorporated to minimize the "back pressure" between the refrigerator liquid reservoir and the refrigerator exhaust port.

Attention will also be focussed, in parallel, on the material problems associated with the long storage life requirement anticipated for a refrigerator with the above mentioned applications. Work will proceed with the objective of 1) eliminating organic materials from the refrigerator or its housing, 2) developing bonding techniques which are compatible with thermal expansion and contraction requirements, and 3) sealing technology which will accomodate long life vacuum and vacuum maintenance requirements.

We now plan to use a miniature "water knife", which has been under construction at MMR, instead of the masks, to facilitate the contour cutting of the glass laminates. Development work will be continued on a high pressure water-knife to be used for the precision cutting of glass slides and glass laminates. Newly designed nozzles will be tested and and an x-y table will be developed for computer controlled cutting of the refrigerator geometries.

3.2 Compressor Development, Assembly and Test

The new design will be tested and control electronics will be developed, tested and integrated with the compressor. The electronics has been designed to utilize Hall sensors to sense the end of the compressor piston stroke, rather than using a timing circuit which is limited because it does not allow a variation of piston speed with load, whereas Hall sensors do.

3.3 Gas Cleaning System, Test and Integration

Various gas gettering technologies will be further investigated as a means of cleaning the gas used in the closed cycle system. Tests of the Reversible Gas Filter/Dryer will be continued to evaluate the benefits of such a cleaning system in a closed cycle system. This Filter/Dryer has the unique characteristic of isolating any gas contaminants and returning them to the compressor where their lubricating properties can be utilized to enhance the life of the compressor seals while allowing only the purified gas to flow through the refrigerator. Tests will be performed with hydrogen and helium to determine that the same beneficial results are obtained as have been observer with nitrogen. Efforts will be initiated to test and study a new gas cleaning resin which does not require operation at an elevated temperature; and which provides cleaning to the parts per billion (ppb) level.

3.4 Software Development

The program which calculates the flow of gas through the cooler as a function of temperature and surface roughness of the different stages of the refrigerator will be further refined. It is expected that this will provide a better understanding of the reasons for the observed discrepancies in the refrigerator flows at the lowest operating temperatures.

4.0 Progress Since End of Last Contract

4.1 Refrigerator Development

Artwork for new prototypes of the two stage refrigerator,

designed using the results of the latest tests and the calculations of the current computer programs, have been fabricated and are ready for use in prototype fabrication.

4.2 Compressor Development

All parts for the latest iteration of the compressor have been receiver and assembled and are ready for testing of the compressor to begin.

4.3 Gas Cleaning System

A reversible gas filter/dryer has been allocated for use with tests with a high temperature getter system.

4.4 Software Development

Computer hardware compatible with the recently developed software has been acquired which will execute the program more quickly and speed the design analysis process.

5.0 Publications

5.1 Cryogenic Engineering Conference

Dr. Little presented two invited papers to this conference held in Los Angeles in July. Many requests have been received for preprints of these papers entitled "Advances in Joule-Thomson Cooling" and "Microminiature Refrigerators for Joule-Thomson Cooling of Electronic Chips and Devices".

These papers drew heavily on the research sponsored by this contract.

6.0 Summary

There have been advances in many areas of the development of the Joule-Thomson cooler for this contract. Significant difficulties remain for completing the project. Attention will be focused on refrigeration fabrication techniques where the technology is being pushed to its limits. Methods and techniques which will provide faster turn-around of prototype refrigerators will be uulized.

7.0 Personnel

The following persons are and will continue to be involved in each of the different development tasks indicated below:

Refrigerator Development and Test
W. A. Little
D. Connell
M. Dubois

Compressor Development and Test
W. A. Little
H. Edman
W-L Chiu
J. Brennan

Software Development and Implementation
W. A. Little
M. DuBois

Gas Cleaning System Development
W. A. Little
M. DuBois

Water Knife Development and Application
W. A. Little
H. Edman
M. DuBois

Respectfully submitted,

Robert L. Paugh